PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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Phil. Trans. R. Soc. Lond. A 1972 **272**, 621-625
doi: 10.1098/rsta.1972.0069

Phil. Trans. R. Soc. Lond. A. **272**, 621–625 (1972) [621]
Printed in Great Britain

Acoustics of concert and multi-purpose halls

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The 1980s are likely to see a continuation of the trend of the past 25 years of an expansion in the quantity, and improvement in the quality, of public music making. Concert halls are usually prestigious buildings, and often no expense is spared to make the acoustics as good as possible, but the design problems are still formidable. In the 1980s some considerable help in design may be expected from scale models and computer simulation. And electronic aids for acoustics may become more common.

The problems of multi-purpose halls are rather different; the conflicting acoustic requirements for speech and for music have to be reconciled, and cost is important. Here electronic techniques may play a considerable part in the future.

Introduction

Ever since the gramophone was invented, it has often been predicted that the days of live performance of music were numbered. Then came the cinema as a threat to the live theatre, and sound broadcasting as a threat, it was said, to both live concerts and live theatre. And then television. So we should ask ourselves – is there any point in discussing the acoustics of auditoria in the 1980s?

I will not discuss cinemas or studios: they are in a technical class on their own; and I will only touch on the acoustical problems of buildings used for religious purposes. The other main types of auditoria – the theatre and the concert-hall and their combination, the multi-purpose hall – are by no means dead, although no doubt the new media, the gramophone, etc., have had a considerable effect on them. I do not think there are any full statistics; some straight theatres and many variety theatres have closed, but many new ones are being built; there never were many concert halls, but it is very rare for one to close (although they often burn down). Such statistics as are known indicate that some 10 to 15 auditoria are being built each year in the U.K. by local authorities, and in addition there are those being built by the Universities, and other institutions. And I am sure there has been a big increase in concert-going. Look at London. Before the war the main halls were the Royal Albert Hall, the Queen's Hall, and the Wigmore Hall. The Queen's Hall is burnt down (incidentally its acoustics were not particularly good: there is nothing like getting burnt down as a way to get a good posthumous reputation for acoustics), but has been replaced by the Royal Festival Hall, which seats 50 % more than the Queen's Hall did, and – more significant – has a concert virtually every day of the week (two or three on some days) compared with the three or four a week in the season at the old Queen's Hall. The Wigmore Hall is still going strong, and so is the Albert Hall (with acoustical improvements). This Hall has about the same number of concerts as before the war, but the Promenade concerts are now held there with much larger audiences than before. And in addition since the war, in London, there have been built the large Fairfield Hall in Croydon, the Queen Elizabeth Hall, and the Purcell Room, and a 2000 seat concert-hall is to be built in the Barbican.

The post-war concert halls I have mentioned have all been built by local authorities, and I suppose no concert-hall, or opera house, of the future will ever be built as a purely commercial venture. This is all part of the general trend of more public spending on the arts. And the big majority of theatres, and multi-purpose halls, are being built by local authorities with only the occasional commercial venture. But wherever the money comes from, it is certain that new auditoria will be built in the 1980s, so there is some point in discussing their acoustical design.

The most famous name in architectural acoustics is Sabine – professor at Harvard between 1895 and 1918, who defined 'reverberation time'. This is the time taken for a sound to decay by 60 dB (i.e. to one-millionth of its original intensity) after the source of sound has stopped. You will not be much interested in technical detail, and I will only say that the reverberation time of an auditorium is still in my view the most important single acoustical factor in the design, and in fact is still – 70 years after Sabine defined it – the only quantitative factor. However much reverberation time may be criticized, correctly, as not telling the whole acoustical story, I doubt if anyone would design a hall without calculating the reverberation time. (The time is in itself not so important: its importance is that it is a measure of the amount of sound absorption present in a room.)

A lot of knowledge has been gained since Sabine's day about how to calculate reverberation time more accurately, but why is it that no other quantitative criteria yet exist? There are two reasons I think. The first is that the behaviour of sound in rooms is an extremely complicated phenomenon. For example, consider the so-called normal modes of vibration. The air in a tube, an organ pipe for example, will resonate at a fundamental (or first harmonic) frequency, plus several higher harmonics, depending mainly on the length of the pipe. Now a room has breadth and height as well as length, so that the air will resonate in many more modes, and in the Royal Society's Welcome Lecture Hall there will be something like 2×10^6 modes in the audio-frequency range. The listener is not usually aware of these modes, but if we play a pure tone out of a loudspeaker, with constant emitted energy, and slowly change the frequency, the loudness will be heard to vary, as the various room resonances are excited.

So the behaviour of the sound is very complicated to start with, and add to this (in the case of music) those very complicated sound sources – muscial instruments, and the even more complicated behaviour of the ear and brain. Aldous Huxley in *Point counterpoint* writes: 'The shaking air rattled Lord Edward's membrana tympani; the inter-locked malleus, incus and stirrup bones were in motion so as to agitate the membrane of the oval window and raise an infinitesimal storm in the fluid of the labyrinth. The hairy endings of the auditory nerve shuddered like weeds in a rough sea; a vast number of obscure miracles were performed in the brain, and Lord Edward ecstatically whispered "Bach"!'.

The second reason for the slow progress in design knowledge is simpler: not much research is done. In this country, the B.B.C. work on a significant scale on the acoustics of studios (which are outside the scope of my talk today), and the Building Research Station works intermittently. It is not a fashionable subject in universities, although things are beginning to change. Fortunately, more work is done in other countries.

Until recently, most research work on the acoustics of auditoria had to be done in real halls, and this was another complication inhibiting research. But two fairly recent developments should make for faster progress. The first is the use of a computer to simulate the effect of room acoustics on speech or music. Even then, the complete room behaviour is too complicated for a computer to deal with, and considerable simplification has to be adopted. A more immediately promising technique is acoustic modelling, and this has been made possible in recent years by the improvements in microphones and loudspeakers and tape recorders so that they can handle frequencies of up to about 100 kHz. The process is simple in theory but complicated in practice. The source material could be music recorded under anechoic conditions, that is with no reverberation. Such a recording is then played back at, usually, eight times the speed and thus at eight times the frequency into a one-eighth scale model. The surfaces of the model have also to be scaled, in the sense that a 'full-scale' surface with a certain absorbent coefficient at a frequency f has in the model to be replaced by a surface with the same absorption at $8f$. This is tricky but not impossible. Another complication is absorption of the sound by air, which only becomes important in the full-scale at about 2 kHz, but affects most of the frequencies used on the model scale. This can be overcome by drying the air in the model to about 3% r.h., when the absorption of sound is then reduced. The music is re-recorded in the model, and is then replayed reduced by a factor of eight in speed, i.e. back to its original speed and frequency. Thus various room designs can be quickly checked, using speech or music for subjective judgements, or using varying sound sources, steady or transient, for objective measurements. The B.B.C. Research Department has built a model 'facility' for their work on studio acoustics, and the B.R.S. is building one for work on theatre and concert-hall acoustics. The B.B.C. has demonstrated that music recordings treated in this way can still preserve their quality sufficiently for subjective judgements to be made.

Now to discuss the acoustical design of auditoria of the 1980s. Let us consider first rooms intended primarily for speech, that is theatres and assembly halls and the like. Compared with music, the acoustic design problems for speech are simple. A fairly short reverberation time, but not too short – about one to one-and-a-quarter seconds – good sight lines, reflecting surfaces to help the sound propagate over the absorbing audience area, absorbent surfaces to stop echoes, and a low background noise. All the factors are well understood, albeit only qualitatively (except for the reverberation time). This is so-called geometric acoustics, i.e. treating sound as if it were light, which it is not, and this does mean that sometimes inexplicable faults occur. The best example I know was in the Shakespeare theatre at Stratford-on-Avon where there used to occur at the back of the circle a concentration of sound arriving about 300 ms after the direct sound from the stage had arrived, and this interfered with the speech intelligibility. This 300 ms delay meant that this sound had travelled about 90 m further than the direct sound, and this could not be explained in geometric terms. It was cured by extra sound absorbent on the side walls, but this is the sort of fault that models, and perhaps computer simulation, would show up.

For the acoustical design of 'pure' theatres, then, I do not see much change in the 1980s from present-day practice, except a greater security of design, and diagnosis of faults, from models and computers, and a general increase in quantitative knowledge, e.g. of the permissible level of echoes before they become destructive of intelligibility. Loud-speakers for speech reinforcement are rarely used in 'pure' theatres (actors can speak naturally and apparently effortlessly about 10 dB louder than other people, that is about twice as loud, or ten times the emitted energy) but for all other speech auditoria loudspeaker reinforcement is becoming more and more common. This is not necessarily a good thing: many speakers rely on them, and apparently believe that a good loudspeaker system will turn mumbly speech into clear speech. Loudspeaker systems will do two things: make the speech louder, and – in reverberant buildings such as cathedrals – reduce the bad effect of excessive reverberation. The loudspeaker column – which directs the speech towards the audience and away from the reverberant spaces – has been the big advance here, plus in appropriate circumstances the use of time delays to reduce interference between many loudspeakers and to maintain naturalness, but there is nothing new in this – our speech reinforcement system in St Paul's Cathedral which was the first to use both loudspeaker columns and time delays, is now twenty years old. (Surprisingly, the U.S.A. has lagged behind Europe in its use of loudspeaker columns.) What we might hope for in the 1980s is an increase in the application of existing knowledge, and an improvement in the maintenance standards. One trouble in the past has been that the large and capable firms have tended to be undercut by the radio shop on the corner, so improvements in the 1980s must come from the clients insisting on good quality, and being willing to pay for it. An extraordinary thing at the present time is that it is difficult to get a time delay loudspeaker system into such an important building as Westminster Abbey, whereas practically every home in the country has a far more complicated piece of electronics, namely a television set. But newer techniques – such as the use of acoustic surface waves, or small computers, to provide the necessary delays may ease this situation. A remarkable recent speech reinforcement system is in the Church of Christ, Scientist, in Chicago, which uses 350 microphones, with appropriate delays, so that any member of the congregation may be heard.

It is in the design and performance of rooms wholly or partly intended for music we can hope for most progress in the 1980s. I think we can disregard what appears to me to be the lunatic fringe of musicians who say that acoustics do not matter, and if the music is drowned by the noise of a passing aircraft this is all part of the contemporary scene: I am sure any architect responsible for spending five or ten million pounds on a new concert-hall will not disregard the acoustics.

As I have said, we so far know very little, and each acoustic consultant has his own preferences. It is generally agreed that a longish reverberation time is desirable, say about 2 s, and longer at the lower frequencies than at the medium and higher frequencies, but should we use an overhead reflector to help the audience at the rear of the hall, or does this make the music sound harsh, and should we perhaps try and get as much lateral reflexion as possible, even if this does mean reducing the space for the choir, and so on. Full-scale experiments are very difficult. In the Queen Elizabeth Hall there is a movable reflector but although it only takes a minute or two to alter it, this delay makes it difficult to judge its effect. Models, I hope, will be the answer, but I have not so far mentioned a big difficulty with models of rooms intended to be listened in, that is as distinct from studios, and it is the problem of subjective judgements with two ears. We can put two microphones into the model on either side of a model head, but how do we present the resulting two signals to the listener?

I mentioned a desirable reverberation time of 2 s for music, and this compares with the 1 s desirable for speech. There is therefore an acoustical problem for multi-purpose halls. Some acoustical changes can be made in a hall by using curtains, or changing by various mechanical means parts of the room surfaces, but the changes achievable by these means are rather small. Further, in the larger concert-halls it is rather difficult to get a reverberation time as long as 2 s, and certainly expensive in terms of the size the hall has to be. For these two reasons, electronic means of controlling the reverberation time have seemed desirable for many years and there are, in my view, two possible systems at the present time. I will not describe either of them in detail, but both rely on the principle of regenerative reverberation, that is introducing into the room some form of feed-back loop or loops. This principle is often demonstrated, inadvertently, when the gain of an ordinary speech reinforcement system is increased too much: the system can be heard to 'ring' at a certain frequency. This 'ringing' is in fact an increase of the reverberation at this one frequency (and this frequency is determined by the positions of the microphone and loud-speaker in the room relative to the positions of the anti-nodes of the modes of vibration of the air in the room). One system employing this principle is being developed by Philips and uses some fifty loudspeakers and microphones distributed randomly throughout the room. As far as I know, full-scale trials of this system are just about to be made. The second system was installed by us in the Royal Festival Hall a few years ago, and consists of 172 microphones and loudspeakers, each microphone dealing with one frequency only. A model of this system is soon to be exhibited in the Science Museum. Time alone will show which of these systems is the better, or quite likely some other system will be invented. Whichever succeeds finally, will make it easier to build large concert-halls, and will make the acoustics of multi-purpose halls less of a compromise, and we might even have an opera-house acoustically suited for both Mozart and Wagner.

The cost of such a system is not significant in comparison with the cost of a new concert-hall or opera-house, but for the general run of multi-purpose halls with limited budgets the cost is important. To gain wide acceptance in multi-purpose halls, it seems likely that the cost of a system should not be more than, say, 20 % of the total cost, that is of the same order as the cost of heating and ventilating systems.

This discussion has been confined to traditional Western music. Electronic music of the future may well require other acoustical conditions, but almost certainly they will be supplied electronically, rather than by alterations to the building. Further, if and when instantaneous change of the acoustics is possible, composers might include such changes in their scores.

Electronic aids of this kind for music raise some interesting ethical problems. It is said that it is not 'natural' for the acoustics to be affected in this way, but then what is natural about a concert-hall, or music itself for that matter? Where do we draw the line? The 6000 audience in the Palace of the Soviets in Moscow hear practically no sound straight from the orchestra: it all comes from a 7-channel stereophonic loudspeaker system on the platform plus reverberant sound from loudspeakers round the walls. This particular system requires the services of a balance and control engineer for each concert, and perhaps we could draw the line here, and say that any electronic system must be a fixed part of the hall.

A more immediate problem is who is to control the acoustics? In ordinary halls the acoustics are more or less determined once and for all by the architect when the hall is designed, but suppose the acoustics can be adjusted instantaneously: does the musician decide this, or the management, or who? And musicians, brilliant as they are, are only human, and if they get a bad review the next morning was it not perhaps due to the acoustics being at the wrong setting?

Such problems will probably fade away, and may have disappeared completely by the 1980s, and electronic aids may be common-place. And it seems certain for multi-purpose halls that the big advantage of having acoustics suitable for speech and music will outweigh any ethical doubts. The Central Hall at York University was designed by the architects to be physically flexible, but the acoustics were designed for speech, i.e. a short reverberation time. A simplified version of our Festival Hall system is now being installed commercially in this Hall, in an attempt to double the reverberation time, and therefore make it excellent for both speech and music.

The work described forms part of the research programme of the Building Research Station of the Department of the Environment and is published by permission of the Director.

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